Department of Biological Sciences
CyanoHAB Services

Prof. Wayne W. Carmichael Int'l phone : (1)-937-775-
3173 3640 Colonel Glen Highway Int'l fax : (1)-937-775-
3320 Dayton, Ohio 45435 USA Electronic mail:
wayne.carmichael@wright.edu

Date: January 5, 2006

To: Central Valley Regional Board c/o Lori Webber, and David Jenkins, University of California Berkeley flocdoc@pacbell.net

From: Wayne Carmichael, Wright State University

Subject: Review – Clear Lake Basin Review Plan

Background:

The Central Valley Region requested that the State Board initiate the external peer review process for the proposed amendments by identifying potential peer reviewers per the requirements of Health and Safety Code Section 57004. The proposed Basin Plan Amendment is tentatively scheduled to be considered by the Regional Board in June 2006. The staff report and supporting technical documents will be ready for review by 1 November 2005. In order to have time to conduct all public noticing by June 2006, we request that the peer review be completed by 15 December 2005.

The proposed amendments will affect all surface waters within the Clear Lake (Lake County) watershed. Clear Lake is listed pursuant to the Federal Clean Water Act, Section 303(d) as impaired due to nutrients. The impairment is due to nuisance blooms of algae, which often occur during the summer and fall in Clear Lake. These conditions lead to the impairment of aquatic life, recreation and municipal beneficial uses of Clear Lake.

They recommended that the State Board solicit reviewers with expertise in water quality modeling, limnology, nutrient cycling, and the causes and control of nuisance blue-green algae blooms in lakes. Attachment one is a summary of the Basin Plan Amendment. Attachment two is a listing of the specific scientific issues that we would like the reviewers to address. Attachment three contains a list of the persons who have participated in the development of this proposal.

Summary:

As a peer reviewer for the Clear Lake Basin Plan Amendment I have read the following documents. My comments emphasize my expertise in limnology, nutrient cycling, and the causes and control of nuisance and toxic blue-green algae blooms in freshwater bodies.

1) Attachment 1-Summary of Basin Plan Amendment
2) Attachment 2-Summary of Technical and Scientific Issues
3) Amendment To The Water Quality Control Plan for the Sacramento River and San Joaquin River Basins For The Control of Nutrients in Clear Lake - Peer Review Draft Staff Report
4) Total Maximum Daily Load for Nutrients in Clear Lake, Lake County, California Technical Report DRAFT December 1st, 2004 Prepared for; Central Valley Regional Water Quality Control Board by Tetra Tech

My comments are primarily directed toward the questions posed to reviewers as provided in Attachment 2-Summary of Technical and Scientific Issues:
****

Reviewer Forward Comments: This Basin Plan for Clear Lake addresses nutrient control as a target against proliferation of algae waterblooms especially cyanobacteria. The cyanobacteria genera present in the Clear Lake waterblooms are a key member of the US "National Plan for Algal Toxins and Harmful Algal Blooms" (HARRNESS, 2005. Harmful Algal Research and Response: A National Environmental Science Strategy 2005-2015. Ramsdell, J.S., D.M. Anderson and P.M. Glibert (Eds.), Ecological Society of America, Washington DC, 82 pp.)

A quote from this document's executive summary is appropriate in supporting the Clear Lake Basin Review Plan, and is given below:

"Harmful algae are those proliferations of microscopic algae that cause harm to the environment, though the production of toxins that accumulate in shellfish or which kill fish, or through the accumulation of biomass that in turn affects co-occurring organisms and alters food webs in negative ways. Like much if the world's coastlines, the coasts of the US have experienced increases in the number, frequency and type of harmful algal blooms (HABs) in recent years. **Freshwaters** are also experiencing these events and impacting inland states. The impacts of such events range from human illness and mortality from direct consumption or indirect exposure to toxic shellfish or toxins in the environment, as well as economic hardships for local communities. Equally important are the devastating impacts HABs may cause to ecosystems, leading to environmental damage that may reduce the ability of ecosystems to sustain species due to habitat degradation, increased susceptibility to disease, and long term alterations to community structure. In short, HABs lead to poisonous seafood, mortality of fish and other animals, economic impacts to coastal communities, losses to aquaculture enterprises, and long-term ecosystem changes."

This HARRNESS report follows on the enactment of two national legislations; 1) The Harmful Algal Bloom and Hypoxia research and Control Act (HABHRCA) of 1998. P.L. 105-1-383; and 2) Harmful Algal Bloom and Hypoxia Amendments Act of 2004. H.R. 1856, House Rpt. 108-326 which reauthorizes HABHRCA. The HABHRCA reauthorization requires an assessment of freshwater HABs that, in the future, would be incorporated into the five-year marine HAB assessments. This emphasizes the importance of controlling cyanobacteria waterblooms as components of the bigger national Harmful Algae Blooms (HABs) programs and policies.
****

The statute mandate for external scientific peer review (Health and Safety Code Section 57004) states that the reviewer's responsibility is to determine "**whether the scientific portion of the proposed rule is based upon sound scientific knowledge, methods and practices**".

We request that you make this determination for each of the following issues that constitute the scientific portion of the proposed regulatory action. An explanatory statement is provided for each issue to focus the review.

1. **The water quality models used are applicable to Clear Lake.**

   Tetra Tech used two water quality models to develop the technical TMDL for Clear Lake. The watershed model used was the Loading Simulation Program in C ++ (LSPC), and the receiving water model used was the Environmental Fluid Dynamics Code (EFDC). These water quality models have been used in TMDL development throughout the country. The models were used to simulate phosphorus loading into the lake and nutrient cycling and algae growth within the lake. Algal growth was represented by simulating chlorophyll-a concentrations during a period of years that represented "compliant" and "non-compliant" conditions.

   <u>Reviewer comments:</u> I have no experience with the two water quality models that Tetra Tech used for the Basin Plan. Therefore I have no comments in the area of model appropriateness, however the following concerns chlorophyll a.
   The choice of chlorophyll-a to represent levels of algal growth is the acceptable method. Prokaryotic Cyanobacteria (blue-green algae) produce Chl-a (but not Chl B) and one of their characteristic pigment groups the phycocyanins can be used to distinguish them from other algal groups. Since cyanobacteria represent the primary algal type present phycocyanins would also have been an acceptable measure of the dominant algal biomass. Depending on how the basin plan is implemented it would be appropriate to use the new technology available for monitoring phycocyanins. Both Hydro Lab and Yellow Springs Instruments Inc. have developed an *in situ* sond probe system using fluorescence technology for continuous monitoring of cyanobacteria phycocyanin.

2. **The phosphorus reduction strategy is appropriate for Clear Lake.**

   Prior studies of Clear Lake point to phosphorus as the ultimate driver of blue-green algae growth. External loading of phosphorus occurs during the rainy season as sediment from the surrounding watershed is eroded. Internal loading of phosphorus occurs during the summer and fall when lower dissolved oxygen conditions favor the release of phosphorus from the sediments, making it available for uptake by blue-green algae. Controlling the external load of phosphorus by reducing erosion in the watershed is expected to reduce external loads of phosphorus and eventually reduce internal loading. Phosphorus exits the system via burial in sediments or outflow to Cache Creek. This process will eventually make less phosphorus available for algae growth, and the frequency and occurrence of nuisance blue-green algae blooms should be reduced or eliminated.

   <u>Reviewer comments</u>: Nutrient and hydrologic conditions strongly influence planktonic and benthic cyanobacterial bloom dynamics in aquatic ecosystems ranging from streams and lakes to coastal ecosystems.

Urbanization, agricultural and industrial development have led to increased nitrogen (N) and phosphorus (P) discharge, which affect cyanobacterial bloom dynamics and their impact on receiving waters. The amounts, proportions and chemical composition of N and P sources can influence the composition, magnitude and duration of blooms. Freshwater systems having low molar ratios of both total and soluble (biologically-available) N to P (<15) are most likely to experience cyanobacterial dominance (Smith 1983, 1990). Conversely, waters having molar N:P ratios in excess of 20 are more likely to be dominated by eukaryotic algal taxa (Smith 1983). (quoted from Paerl 2005)

Smith VH (1983) Low nitrogen to phosphorus ratios favor dominance by blue-green algae in lake phytoplankton. Science 221:669-671

Smith VH (1990) Nitrogen, phosphorus, and nitrogen fixation in lacustrine and estuarine ecosystems. Limnol Oceanogr 35:1852-1859.

Paerl, H. W. Nutrient and other environmental controls of harmful cyanobacterial blooms along the freshwater-marine continuum. In Proceedings of International Symposium on Cyanobacterial Harmful Algal Blooms (ISOC-HAB), September 6-10, 2005, Research Triangle Park, NC, USEPA.

The N:P rations recorded for Clear Lake (between 7 and 15, Table 3-1) are in agreement with the published literature. This reviewer is in agreement that internal and external loading of phosphorus is a key component of the algae bloom (in particular cyanobacteria blooms) problem in Clear Lake. Reduction of external loading to the compliance levels reported will reduce total P inputs and allow, over time, a reduction in available total P. Internal P loading will also be reduced (over a longer period of time). The target date of 2011 should allow sufficient time for internal loads to be reduced but it is not clear that internal loading will be reduced. One recommendation would be to study the conditions for internal loading (in addition to dissolved oxygen and temperature) and try and determine if time would influence a change in P release from the sediments.

3. **There is a link between chlorophyll-a and phosphorus in Clear Lake.**

   Chlorophyll-a was chosen as the target constituent for this TMDL. Chlorophyll-a is a surrogate measure of the amount of algae in the water column. Algae growth is fueled by the nutrients phosphorus and nitrogen. Some blue-green algae species fix atmospheric nitrogen and therefore have a competitive advantage over other types of aquatic plants when phosphorus levels are high. During the summer and fall internal loading of phosphorus causes large quantities of this nutrient to be present in the water column, increasing concentrations and favoring the growth of blue-green algae.

   Reviewer comments: Since P is a key limiting nutrient in algal growth and the N:P ratios in Clear Lake favor Cyanobacteria growth, and since Cyanobacteria contain Chl a, linking Chl-a and P is appropriate. Prokaryotic Cyanobacteria also produce the more characteristic pigment for their group – Phycocyanin. This pigment can be used to distinguish them from other

algal groups. Since cyanobacteria represent the primary algal type present phycocyanin would also have been an acceptable measure of the dominant algal biomass. Depending on how the basin plan is implemented it would be appropriate to use the new technology available for monitoring phycocyanin. Both Hydro Lab and Yellow Springs Instruments Inc. have developed an *in situ* sond probe system using fluorescence technology for continuous monitoring of cyanobacteria phycocyanin.

4. There is a link between water clarity and algal growth in Clear Lake.

Another potential surrogate measure of algal growth is water clarity. In Clear Lake water clarity has been measured using a secchi disk since 1969. During the summer and fall the clarity of the water is primarily affected by algae biomass.

Reviewer comments: Water clarity can be influenced by factors such as suspended materials (sediments etc), but in Clear Lake clarity is influenced mainly by algal biomass. In the summer the algae that dominate are the planktonic Cyanobacteria *Anabaena, Aphanizomenon* and *Microcystis*. During summer, when runoff subsides, externally-supplied P loads (from point sources) or internally-generated P loads released from hypoxic sediments tend to contribute more to nutrient loading. P enrichment (declining N:P ratios) can select for N2 fixing species-also called diazotrophic species. In Clear Lake these are represented mainly by *Anabaena and Aphanizomenon*. Non-diazotrophic species, represented in Clear Lake mainly by Microcystis, can remain a significant fraction of the phytoplankton as they are able to utilize fixed N produced and released by N2 fixers. Using water clarity measurements via a secchi disc is an acceptable indicator of nutrient conditions if it used in conjunction with phytoplankton and nutrient monitoring.

5. Overarching questions.

Reviewers are not limited to addressing only the specific issues presented above. Additionally, we invite you to provide input on the following “big picture” questions.

(a) In reading the staff technical reports and proposed language, are there any additional scientific issues that are part of the scientific basis of the proposed amendments not described above? If so, please comment with respect to the statute language given above.

Reviewer comments: on the Amendment To The Water Quality Control Plan for the Sacramento River and San Joaquin River Basins For The Control of Nutrients in Clear Lake - Peer Review Draft Staff Report

This reviewer agrees with the staff report summary. If the comments in the rest of this review are considered the Basin Plan for Clear Lake will have a good chance of reversing the eutrophication status of Clear Lake and its cyanobacteria harmful algae blooms.

(b) Taken as a whole, is the scientific portion of the proposed rule based upon sound scientific knowledge, methods, and practice.

Reviewer comment: Yes the scientific portion of the proposed rule is based upon sound science.

Reviewers should also note that some proposed actions may rely significantly on professional judgment where available scientific data are not as extensive as desired to support the statute requirement for absolute scientific rigor. In these situations, the proposed course of action is favored over no action.

The preceding guidance will ensure that reviewers have an opportunity to comment on all aspects of the scientific basis of the proposed Board action. At the same time, reviewers also should recognize that we have a legal obligation to consider and respond to all feedback on the scientific portions of the proposed rule. Because of this obligation, we encourage you to focus your feedback on the scientific issues that are relevant to the central regulatory elements being proposed.

Additional reviewer comment: The dominant cyanobacteria phytoplankton in Clear Lake, *Anabaena, Aphanizomenon and Microcystis* (the notorious trio, "Annie, Fannie and Mike") can form metalimnetic blooms in nutrient enriched (N and P) lakes and reservoirs. Odor and taste producing episodes co-occur under these circumstances. In clearer waters where light reaches the bottom, benthic N_2 fixing and non-fixing assemblages (e.g. Lyngbya, Oscillatoria, Microcoleus, Scytonema, Phormidium) can predominate. Mixed assemblages often persist as a bloom "consortium" during summer and fall, until unfavorable physical conditions such as cooling (<15 ^{o}C) and water column turnover take place. The three genera *Anabaena, Aphanizomen and Microcystis* are also the three main cyanobacteria producers of potent toxins called cyanotoxins (Carmichael, 1997, 2001; Carpenter and Carmichael 1995).

Cyanobacteria toxins (cyanotoxins) include cytotoxins and biotoxins with biotoxins being responsible for acute lethal, acute, chronic and sub-chronic poisonings of wild/domestic animals and humans. The biotoxins include the neurotoxins; anatoxin-a, anatoxin-a(s) and saxitoxins plus the hepatotoxins; microcystins, nodularins and cylindrospermopsin (Carmichael et al. 2001, Chorus and Bartram 1999).

If blooms of these toxigenic cyanobacteria continue to occur they should be monitored for cyanotoxins and appropriate management and mitigation programs be put in place. The current basin plan for Clear Lake will certainly help in moderating and reducing these potentially lethal bloom forming cyanobacteria.

Carmichael, W.W. 1997. The Cyanotoxins. in Advances in Botanical Research (ed Callow, J.) 27, 211-256 Academic Press, London.

Carmichael, W.W. 2001. Health Effects of Toxin Producing Cyanobacteria: "The CyanoHABS". Human and Ecological Risk Assessment. 7(5): 1393-1407.

Carmichael, W.W., Azevedo, M.F.O., An, J.S., Molica, R.J.R., Jochimsen, E.M., Lau, S., Rinehart, K.L., Shaw, G.R., Eagelsham, G.K. 2001. Human Fatalities from Cyanobacteria: Chemical and Biological Evidence for Cyanotoxins. Environmental Health Perspectives. 109 (7):663-668.

Carpenter, E.J., Carmichael, W.W. 1995. Taxonomy of Cyanobacteria. in Hallegraeff, G.M. et al. (eds.) Manual on Harmful Marine Microalgae p. 373-80. IOC Manuals and Guides No. 33 UNESCO.

Chorus, I., Bartram, J. (eds.) 1999. Toxic Cyanobacteria in Water: A Guide to Their Public Health Consequences, Monitoring and Management. World health Organization, E&FN Spon, Routledge, London.

Note: On page 13 and 21 of the Tetra Tech CL Draft—*Aphanizomenon* is spelled incorrectly.

Respectfully submitted

January 14, 2006

Wayne W. Carmichael
Professor-Aquatic Biology/Toxicology
Department of Biological Sciences
Director of Environmental Sciences PhD Program
Wright State University
Dayton, Ohio 45435
Tel: 937-775-3173
Email: wayne.carmichae@wright.edu